

PRODUCTIVITY MEASUREMENT AT THE MICRO LEVEL

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Abstract

This paper presents a general introduction to productivity measurement at the micro level. First, the concept of productivity is discussed and a mathematical definition is introduced. Next, various issues on productivity measurement, including index numbers, classification of inputs and outputs, and knowledge workers, are extensively discussed.

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Productivity has recently become one of the most widely discussed issues. Numerous productivity figures are cited every day to support a variety of arguments. Decision makers, in both government agencies and private organizations, rely more and more on productivity information in conducting their affairs. Nevertheless, the concept of productivity still remains elusive and people tend to use the term arbitrarily.

In this paper, we present a general introduction to productivity measurement at the micro level. The concept of productivity is discussed and a specific mathematical definition is introduced. Under this definition, various quantification and qualification issues on productivity measurement are extensively discussed. The paper focuses on the micro, rather than macro, level. Therefore, the discussion applies to a single production activity, a division of a firm, as well as a whole firm.

1. A Broad Concept of Production

In this paper, we use the word "production" in a broad sense and define it as an activity which converts a basket of goods and services (inputs) into another basket of goods and services (outputs). Figure 1.1 illustrates this point.

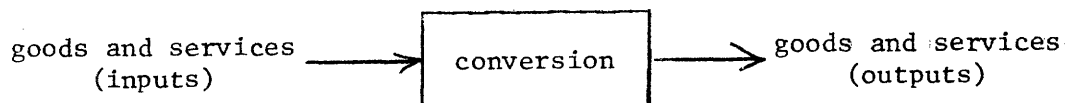


Figure 1.1 Concept of Production

Within this definition, purchasing raw materials, manufacturing, transporting, stocking, and retailing goods are all production activities. Other

production activities include advertising, research and development (R&D), financial investments, and financing activities. Table 1.1 outlines the possible inputs and outputs of each of the production activities mentioned above.

For the sake of clarity and ease of analysis, a production activity may be disaggregated into several sub-activities or join others to define an expanded activity. For instance, retailing goods may be further disaggregated into personal selling and bill collection, while stocking raw materials and manufacturing goods may be aggregated together to become an expanded activity.

From the viewpoint of economics, all production activities are intended to create utility. Utility is the subjective satisfaction individuals can derive from consuming a basket of goods and services. For instance, an individual derives utility from intake of food or watching a film. The food is physically digested by him while the film is not; but both give him satisfaction. In the case of a film, he is said to consume the leisure service of the film. Other examples of services include the legal service of a lawyer, the medical service of a doctor, the information service of a magazine, the transportation service of a car, and the food-keeping service of a refrigerator.

Not all the goods and services of our economy are consumable by individuals. Consider a machine operated in a factory; neither the machine itself nor its manufacturing service is consumable by individuals. However, the unconsumable goods and services participate in a sequence of production activities which eventually lead to something consumable by individuals. A production activity, no matter whether its output is consumable by individuals or not, is intended to create utility which individuals can derive from the final consumable goods and services made possible by this and other related production activities.

Economists sometimes name the utility after the nature of the production activity involved. For example, form utility is created by a production activity which changes the shape of goods so that they are suitable for individuals'

Table 1.1 Inputs and Outputs of Some Production Activities

<u>Inputs</u>	<u>Production Activity</u>	<u>Outputs</u>
Cash Human resources etc.	1. Purchasing raw materials	raw materials
Raw materials (in period t) Warehouse Cash etc.	2. Stocking raw materials in a warehouse	raw materials (in period t+1)
Raw materials Cash Human resources Machines etc.	3. Manufacturing goods	finished goods
Finished goods (at factory) Human resources Vehicles etc.	4. Transporting finished goods	finished goods (at city xx)
Finished goods Human resources etc.	5. Retailing	cash
Cash Human resources etc.	6. Advertising	consumers' knowledge about the firm's products
Raw materials Human resources Machines etc.	7. R&D	technology
Cash	8. Financial investment	cash
Cash (repayments)	9. Financing activity	cash (loan received)

consumption or utilization as inputs of other production activities, time utility is created by a production activity which stores goods and dispenses them when they are needed by consumers or other production activities, and place utility is created by a production activity which transports goods to the places where they are needed by consumers or other production activities [1]. Depending upon its scope, a production activity can create more than one kind of utility. For instance, an activity to stock goods in a warehouse creates time utility while an activity to manufacture, transport, and stock goods creates three kinds of utility: form, place, and time. Although a production activity is intended to create utility, it is not bound to do so. Utility may actually be reduced by an activity which produces bad quality output.

2. Concept and Definition of Productivity

Productivity measures the efficiency with which a production activity converts inputs into outputs. Ideally, productivity should measure the efficiency in terms of input and output utilities since a production activity is intended to create utility. As discussed earlier, unconsumable goods and services participate in a sequence of production activities which eventually lead to something consumable by individuals; hence, a portion of the utility individuals derive from the final consumable goods and services can be assigned to those unconsumable. As a result, utility can be attached to both consumable and unconsumable goods and services. Nevertheless, it is difficult in practice to either quantify the utility individuals derive from the consumable goods and services or assign it to those unconsumable in a satisfactory manner. The reason is the highly abstract nature of the utility of individuals as a group. Because of this difficulty, productivity is usually not defined, in practice,

in terms of input and output utilities.

In this discussion, productivity will be defined as a family of ratios of output to input quantities. This is the most commonly accepted definition in practice. However, the heterogeneity of inputs and outputs must be emphasized before we expound upon this definition. Usually more than one input is involved in a production activity. These inputs are heterogeneous and have their individual denominations. For instance, 50 man-hours of skilled worker, 20 man-hours of semi-skilled worker, 30 pounds of cotton, and 60 machine-hours are different types of inputs and have different denominations. Note that one man-hour of skilled worker and one man-hour of semi-skilled worker are different denominations. To carry out the calculation of ratios of output to input quantities, these heterogeneous inputs must be aggregated in a meaningful way. To this end, each input needs a conversion factor to restate its quantity from the original denomination to a common denomination which is chosen for all the inputs involved. The same must be done with the outputs. However, the common denomination chosen for inputs need not be identical with that for outputs. For example, it is usual to have man-hour as the common denomination for inputs and dollar as the common denomination for outputs. Depending on the common denomination chosen, the conversion factor of each input or output changes accordingly. Alternatively, the conversion factors can be regarded simply as the weights assigned to the inputs and outputs; and the aggregation of heterogeneous inputs or outputs can be regarded as a means to obtain a weighted average of input or output quantities.

Clearly, two fundamental issues are involved in measuring productivity: quantification and qualification. The quantification issue consists in measuring inputs and outputs when they are stated in their original denominations while qualification is the process of converting different inputs and outputs into their respective common denominations.

We next provide a formal definition of productivity:

For any production activity, let

I = set of all input indices

J = set of all output indices

q_t^i = quantity (in the original denomination) of input i employed in period t

Q_t^j = quantity (in the original denomination) of output j produced in period t .

A ratio of the form

$$\frac{\sum_{j \in J} w^j Q_t^j}{\sum_{i \in I'} w^i q_t^i}$$

where w^i = conversion factor (or weight) of input i

w^j = conversion factor (or weight) of output j

I' = a subset of I

is a productivity ratio in period t with respect to input set I' . Productivity in period t is then a family of ratios, of the type defined above, with different subsets of I and/or different conversion factors.

The length of a period should be determined by the basic requirements of productivity ratios, which will be discussed in section 3. It suffices now to say that the shorter the period, the stronger the impact of random disturbances.

A productivity ratio in one period is usually compared with the same productivity ratio in another period for the same production activity or with the same productivity ratio in the same period but for another similar activity. The former is an example of time-series comparison while the latter is an example of cross-sectional comparison. In the time-series comparison, we

need a base period with which any other period (referred to as a measured period) can be compared; and in the cross-sectional case, we need a base section with which any other section can be compared. In our discussion, base period is always indexed by $t = 0$. Unless specified otherwise, we focus on the time-series comparison. Nevertheless, much of our discussion is also applicable to the cross-sectional analysis.

A distinction is usually made between stock variables and flow variables. A stock variable measures the quantity of an item at a point in time while a flow variable measures how the quantity of an item changes during a period of time. Productivity ratios, income-statement items, and fund-statement items are examples of flow variables while balance-sheet items are examples of stock variables.

As defined earlier, productivity is a family of productivity ratios which are constructed by changing the conversion factors or by changing the inputs to be included in the denominator. We shall discuss conversion factors in section 4. Changing the inputs to be included in the denominator is an attempt to detect how different types of inputs are related to outputs. If all the inputs employed by the production activity are included in the denominator, the ratio is said to be a total productivity measure; otherwise, it is called a partial productivity measure. Sometimes, a productivity ratio is named after the inputs involved. If the denominator contains labor inputs only, the resulting productivity ratio is called a labor productivity ratio; and if the denominator contains both labor inputs and capital inputs, the resulting productivity ratio is called a total factor productivity ratio [7]. Similarly, other names such as capital productivity ratio or energy productivity ratio would be appropriate if the denominator contained capital inputs or energy inputs only.

However, the reader should be careful when reading the literature because

two productivity ratios may mean two different things even if they share the same name. For example, the labor productivity ratio of a firm may exclude the white-collar employees from its denominator while the labor productivity ratio of another firm does not. The existence of different treatments is largely due to the different compromises made among the basic requirements of productivity measurement, to be discussed in the next section.

3. Basic Requirements of Productivity Measurement

The basic requirements of productivity measurement outlined below are largely borrowed from accounting theory [5]. Although productivity and accounting may focus on different aspects of a firm, they share many basic requirements as far as measurement is concerned. The basic requirements of productivity measurement include (1) relevance, (2) materiality, (3) consistency, (4) comparability, (5) objectivity, (6) unbiasedness, and (7) cost consideration.

(1) Relevance. Productivity is measured in order to facilitate the task of decision-makers, inside or outside the firm, to make a decision. Productivity information is used differently by different groups. Managers use it to plan and control; creditors and stockholders, to evaluate the firm's performance; government agencies, to decide the macroeconomic policies; negotiators for both the employers and the employees, to bargain with each other; supervisors, to decide the bonuses and promotions of their subordinates; and employees, to check how well they have performed. Hence, productivity must be measured in such a way that the resulting information is relevant for its users in making a decision. Since different users have different needs, it is expedient to measure productivity only after the potential users of the productivity information have been identified. To serve different users may mean to construct different productivity ratios. Of course, the information must be timely for

it to be relevant.

(2) Materiality. Users of the productivity information usually have limited ability to process details; too much detail may be just as misleading as too little. Consequently, productivity measurements should be concerned with information that is material enough to affect decisions.

(3) Consistency. The same measurement procedures should be used for all the periods under comparison in order to facilitate the time-series comparison made by users; otherwise, the users may have difficulty in telling what percentage of change in a productivity figure has been caused by a real change in production efficiency and what percentage has been caused by a change in the measurement procedure. However, a procedural change should still be made if it will result in more useful information for users. When a change is made, it should be made clear to users.

(4) Comparability. The same, or similar, measurement procedures should be applied to all the divisions under comparison. The purpose of comparability is to facilitate the cross-sectional comparisons made by the users of the productivity information.

(5) Objectivity. Productivity measurements should be based upon either verifiable evidence or opinions of qualified experts which result in a narrow statistical dispersion.

(6) Unbiasedness. Productivity measurement should be an unbiased estimator of the true productivity; that is, the expected value of the measurement should be equal to the true value.

(7) Cost consideration. Like any other investment made by the firm, the cost of the productivity measurement procedures should be low enough so that the expected benefit exceeds the cost. In many cases, the high cost of data acquisition and system implementation forces firms to select less costly but also less sophisticated measurement procedures.

4. Conversion Factors (Weights)

The qualification issue is usually difficult to solve for both tangible and intangible goods, while the quantification issue is generally easy to solve for tangible goods but not for intangible goods. In this section, we shall address qualification in general assuming that the quantification problem has already been solved. More specific discussions on qualification and quantification will be presented in sections 6, 7, and 8.

The qualification issue consists in determining conversion factors (weights). We should emphasize that the conversion factors are supposed to remain unchanged over the periods under comparison regardless of how they are determined. If for some reason a change has to be made on the conversion factors, this change should be applied to all the relevant periods which means that we may have to recalculate the productivity ratios for the previous periods if necessary.

The ideal conversion factors, from the viewpoint of economics, would be those that convert input and output quantities into input and output utilities. As mentioned in section 2, we are not able to deal with group utility in a satisfactory manner due to its highly abstract nature. Therefore, we have to turn to other alternatives.

The basic concern here is how to choose the conversion factors in such a way that all the inputs and outputs can be meaningfully restated in their common denominations. Suppose that 200 man-hours of skilled worker and 150 man-hours of semi-skilled worker are involved in the denominator of a productivity ratio. We may use the man-hour of skilled worker or the man-hour of semi-skilled worker or some other units as the common denomination of input. After deciding which common denomination to use, we still have to decide how to convert 200 man-hours of skilled worker and 150 man-hours of semi-skilled worker. It is difficult to make the second decision because we

are dealing with the issue of quality. There is no doubt that one man-hour of skilled worker has a better quality than one man-hour of semi-skilled worker; hence the conversion factors of the two inputs have to quantify the quality difference between them. Suppose that we can argue that the quantified quality of one man-hour of skilled worker is twice as large as that of semi-skilled worker due to the fact, for example, that two semi-skilled workers must operate a machine together while one skilled worker can do it alone. Consequently, the conversion factor for skilled workers is made twice as large as that for semi-skilled workers. Conceivably, a different argument can lead to a different set of conversion factors. Thus, art and science are both needed to determine suitable conversion factors. More problems arise when a total factor productivity ratio is constructed and we have to decide how to convert 200 man-hours of skilled worker, 150 man-hours of semi-skilled worker, and 250 machine-hours into whatever common denomination has been chosen for inputs. In addition to the quality issue between skilled workers and semi-skilled workers, the conversion factors have to take care of two completely different types of inputs: labor and capital. Output does not impose an easier task than input. The conversion factors of outputs have to take care of model change, quality change, and new products which complicate the aggregation of heterogeneous outputs.

A variety of conversion factors have been associated with productivity ratios. Standard unit man-hour, standard unit machine-hour, standard unit cost, standard unit labor cost, base-period unit cost, base-period unit labor cost, base-period unit price, and base-period unit value added are often used as conversion factors for outputs. Equivalent man-hour, equivalent machine-hour, standard unit price and base-period unit price are often used as the conversion factors for inputs.

Price-related conversion factors, such as unit cost, unit price, and unit value added, are very popular. Their popularity comes as no surprise because

on one hand prices are commonly used to evaluate the underlying goods and services and on the other hand prices can be verified from sales/purchase invoices or other sources. The prices have also some implications on utility. As mentioned earlier, production is intended to create utility and utility is the subjective satisfaction that individuals can derive from consuming a basket of goods and services. Given a fixed budget with which an individual can spend on consumable goods and services and a fixed price for each good or service , it has been well-known in economics, [6], that the individual will consume any pair of goods or services, say X and Y, in such quantities that

$$\frac{\text{utility derived from the last unit of X consumed (marginal utility of X)}}{\text{utility derived from the last unit of Y consumed (marginal utility of Y)}} = \frac{\text{Price of X}}{\text{Price of Y}}$$

However, the relation between marginal utility and price as shown above cannot totally justify the use of price as conversion factor in a productivity ratio since it is arguable whether productivity should be concerned with total utility or marginal utility. Another known result in economics, [6], relates output quantity and input price in production. Given a fixed price for each input and a fixed quantity of output to be produced, the least-cost combination of inputs is derived when any pair of inputs, say X and Y, are employed in such quantities that

$$\frac{\text{increase in the quantity of output made possible by the last unit of X employed}}{\text{increase in the quantity of output made possible by the last unit of Y employed}} = \frac{\text{Price of X}}{\text{Price of Y}}$$

Here it is the marginal output quantity, instead of total output quantity, that relates to input prices. Hence, this relationship cannot totally justify the use of input price as input conversion factor either.

Nevertheless, dollar usually becomes the last resort of common denomination whenever other measurement units exhibit greater operational difficulties.

A variant of price is sometimes used as the conversion factor of output when dollar is chosen as the corresponding denomination. The variant is the so-called "unit value added", which is directly borrowed from the value-added concept in economics. Strictly speaking, the unit value added refers to the value added to one unit of an output by a partial input set. The concept of unit value added is best illustrated by an example. Suppose that a production activity involves three types of inputs and two types of outputs. The quantity of each input employed to produce one unit of each output is

	<u>One unit of output 1</u>	<u>One unit of output 2</u>
Raw material (in pounds)	3	5
Labor (in man-hours)	6	4
Capital (in machine-hours)	1	2

The input and output prices are given as follows:

<u>Input or output</u>	<u>Price</u>
Raw material	\$11/pound
Labor	\$4/man-hour
Capital	\$5/machine-hour
Output 1	\$80/unit
Output 2	\$100/unit

The unit value added by each partial input set to one unit of each output is calculated as follows:

Value added by partial input set to one unit of

<u>Partial Input Set</u>	<u>Output 1</u>	<u>Output 2</u>
Raw material	$\$51 = \$80 - (\$4 \times 6 + \$5 \times 1)$	$\$84 = \$100 - (\$4 \times 4 + \$5 \times 2)$
Labor	$\$42 = \$80 - (\$11 \times 3 + \$5 \times 1)$	$\$35 = \$100 - (\$11 \times 5 + \$5 \times 2)$
Capital	$\$23 = \$80 - (\$11 \times 3 + \$4 \times 6)$	$\$29 = \$100 - (\$11 \times 5 + \$4 \times 4)$
Labor & capital	$\$47 = \$80 - \$11 \times 3$	$\$45 = \$100 - \$11 \times 5$
Labor & raw material	$\$75 = \$80 - \$5 \times 1$	$\$90 = \$100 - \$5 \times 2$
Capital & raw material	$\$56 = \$80 - \$6 \times 4$	$\$76 = \$100 - \$6 \times 4$

The unit value added to an output by a partial input set equals the unit price of the output minus the cost of all other inputs employed to produce one unit of the output. Suppose that a labor productivity ratio is to be computed and that the conversion factor of outputs has been chosen to be the unit value added by labor. Then the numerator of the labor productivity ratio is

$$\$42 Q_t^1 + \$35 Q_t^2,$$

where Q_t^1 and Q_t^2 are the quantities of outputs 1 and 2, respectively, in period t . Suppose that a total factor (labor and capital) productivity ratio is to be computed and that the conversion factor of output is the unit value added by labor and capital. Then, the numerator of the total factor productivity ratio is

$$\$47 Q_t^1 + \$45 Q_t^2.$$

The value added by a partial input set does not represent the "true" value contributed by the set unless all the markets (including various markets of goods and services and financial markets) in the economy are perfect and in equilibrium. However, value-added is more meaningful, at least conceptually, than price as the conversion factor of output in a corresponding partial productivity ratio.

Ideally, the value-added conversion factor should be fine tuned to match the inputs involved in a partial productivity ratio. In practice, it may be difficult to do so sometimes. The difficulty arises when, for example, several different outputs share one input and it is not clear how much input quantity should be related to a particular output. The value-added used by many so-called "value-added per man-hour ratio" actually equals the output price minus the material cost, instead of the price minus the sum of the material and capital costs, due to the fact that the allocation of capital cost among various outputs is difficult. The bias would not be large as long as the capital cost is not significant.

As mentioned earlier, a conversion factor is supposed to remain unchanged over all the periods under comparison. As a result, the conversion factor, no matter whether it is the price, the value-added, or something else, should represent impartially the condition prevailing in all the periods under comparison. If a conversion factor is based upon the base-period condition, then we must be sure that the base-period condition is not abnormal. A conversion factor is sometimes obtained by averaging over several periods to eliminate potential irregularity exhibited by any individual period. If conditions change significantly over time, a new conversion factor must be determined and productivity ratios of previous periods should be recalculated using the new factor.

5. Index Numbers

A productivity ratio has the following form:

$$\frac{\sum_{j \in J} W^j Q_t^j}{\sum_{i \in I'} w^i q_t^i}$$

where W^j , w^i , Q_t^j , q_t^i , J and I' were defined in section 2. Suppose that each

output uses its base-period price, denoted by p_o^j for output j , as the conversion factor. The numerator of the productivity ratio becomes $\sum_{j \in J} p_o^j Q_t^j$. If Q_t^j for all $j \in J$ are known, then it is straightforward to calculate $\sum_{j \in J} p_o^j Q_t^j$. However, it is costly to keep all the data on output quantities if the number of outputs involved is large. A detour is devised by using price indices to avoid keeping all the quantity data. Let

$$p_t^j = \text{price of output } j \text{ in period } t.$$

The detour to calculate, for example, $P_o^1 Q_t^1 + P_o^2 Q_t^2$ is based upon the following mathematical equivalence:

$$P_o^1 Q_t^1 + P_o^2 Q_t^2 = \frac{P_t^1 Q_t^1 + P_t^2 Q_t^2}{\left(\frac{P_t^1 Q_t^1 + P_t^2 Q_t^2}{P_o^1 Q_t^1 + P_o^2 Q_t^2} \right)},$$

where $\left(\frac{P_t^1 Q_t^1 + P_t^2 Q_t^2}{P_o^1 Q_t^1 + P_o^2 Q_t^2} \right)$ is called the Paasche price index. This index is obtained by using the measured-period (i.e., period t in our case) quantities as weights.

In many cases, $P_t^1 Q_t^1 + P_t^2 Q_t^2$ can be obtained from accounting records without actually knowing Q_t^1 and Q_t^2 . For instance, $P_t^1 Q_t^1 + P_t^2 Q_t^2$ may represent the value of products 1 and 2 produced in period t and it can be obtained from the sales revenue, which is usually available, of products 1 and 2 in period t with inventory adjustment. If we also know the Paasche price index, then we can easily calculate $P_o^1 Q_t^1 + P_o^2 Q_t^2$ by using the previous mathematical equivalence. However, the Paasche price index cannot be calculated until Q_t^1 and Q_t^2 are known; and if Q_t^1 and Q_t^2 are known, the Paasche price index is really not necessary since $P_o^1 Q_t^1 + P_o^2 Q_t^2$ can be directly calculated in this case. To resolve this dilemma, the detour has to use another suitable price index instead of the Paasche price index.

The choice of a surrogate price index is usually based upon the following two criteria:

- (1) It should be easy to obtain; and
- (2) It should not deviate too much from the Paasche price index.

The second criterion also motivates researchers and practitioners to divide all the outputs into several categories so that the surrogate and the Paasche price indices for each category do not differ significantly. The surrogate price indices are often obtained from trade journals and government publications or constructed by the firm itself in a simplified way. The firm may choose several significant items from a category and then construct a price index solely based upon these selected items. Implicit herein is that the price movement of the omitted items is similar to that of the selected items. Note that a price index whose base period does not coincide with the base period chosen for the productivity ratio must be adjusted appropriately to avoid complications in the interpretation of the resulting productivity figures.

The detour discussed earlier can be summarized as follows:

$$\begin{aligned}
 \sum_{j \in J} p_o^j Q_t^j &= \sum_k \sum_{j \in J_k} p_o^j Q_t^j \\
 &= \sum_k \frac{\sum_{j \in J_k} p_t^j Q_t^j}{\sum_{j \in J_k} p_o^j Q_t^j} \\
 &= \sum_k \frac{\sum_{j \in J_k} p_t^j Q_t^j}{\text{Paasche price index for } J_k} \\
 &\approx \sum_k \frac{\sum_{j \in J_k} p_t^j Q_t^j}{\text{Surrogate price index for } J_k}
 \end{aligned}$$

where J_k = set of indices of outputs in output category k .

Suppose that each input uses its base-period price, denoted by p_0^i for input i , as the conversion factor. Then, the denominator of the productivity ratio becomes $\sum_{i \in I'} p_0^i q_t^i$. Again, a detour can be used here and we have

$$\sum_{i \in I'} p_0^i q_t^i = \sum_k \frac{\sum_{i \in I'_k} p_t^i q_t^i}{\text{Paasche price index for } I'_k} \approx \sum_k \frac{\sum_{i \in I'_k} p_t^i q_t^i}{\text{Surrogate price index for } I'_k}$$

where I'_k = set of indices of inputs in input category k .

Can we use a similar detour if the conversion factors are not prices? The answer is yes. The general forms are:

$$\sum_{j \in J} w_t^j q_t^j = \sum_k \frac{\sum_{j \in J_k} w_t^j q_t^j}{\text{Paasche W index for } J_k} \approx \sum_k \frac{\sum_{j \in J_k} w_t^j q_t^j}{\text{Surrogate W index for } J_k}$$

for outputs and

$$\sum_{i \in I'} w_t^i q_t^i = \sum_k \frac{\sum_{i \in I'_k} w_t^i q_t^i}{\text{Paasche w index for } I'_k} \approx \sum_k \frac{\sum_{i \in I'_k} w_t^i q_t^i}{\text{Surrogate w index for } I'_k}$$

for inputs.

Very often a productivity index is constructed in the following way:

$$\text{Productivity index in period } t = \frac{\text{productivity ratio in period } t}{\text{productivity ratio in period } 0}$$

Obviously, the productivity index in the base period (period 0) is always 1.

The productivity index is actually the ratio of output quantity index to input quantity index, as shown below.

Productivity index in period t = $\frac{\text{productivity ratio in period t}}{\text{productivity ratio in period 0}}$

$$= \frac{\sum_{j=1}^n w^j_{Q_t} / \sum_{i=1}^m w^i_{q_t}}{\sum_{j=1}^n w^j_{Q_0} / \sum_{i=1}^m w^i_{q_0}}$$

$$= \frac{\sum_{j=1}^n w^j_{Q_t} / \sum_{j=1}^n w^j_{Q_0}}{\sum_{i=1}^m w^i_{q_t} / \sum_{i=1}^m w^i_{q_0}}$$

$$= \frac{\text{quantity index of output in period t}}{\text{quantity index of input in period t}}$$

Quantity indices provide an alternative to calculate a productivity index.

6. Inputs

Economists classify inputs into three categories: human resources, natural resources, and capital goods. Human resources obviously include manpower only. Natural resources include land, forest, mineral ores, and animals. These two resources are called primary factors of production since their existence is due to biological or physical reasons rather than economic reasons. On the other hand, capital goods (tangible or intangible) are the outputs of some production activities in an economic system and can be employed, if needed, as inputs by other production activities. Examples of capital goods include machines, warehouses, parts, and technology. As one can imagine, more and more human resources and natural resources can be classified into this category. Education (a production activity) upgrades the quality of human resources; and soil conservation (a production activity) upgrades the quality of land. Consequently, both a medical doctor and a piece of cultivated land can be classified as capital goods, although such classification is an awkward practice.

The construction of productivity ratios is quite flexible. On the one hand, each input (say, a medical doctor or a piece of cultivated land) can exist by itself and a productivity ratio can be defined with respect to it alone. On the other hand, each input can join some other inputs to form a new category and a productivity ratio can be defined with respect to the new category. It does not matter how an input category is constructed or how it is named, as long as its content is made clear to the users and it makes practical sense.

Very often it is the services offered by human resources, natural resources, and capital goods which are the actual inputs of production activities. For instance, the services offered by manufacturing equipment (rather than the equipment itself) are the actual inputs employed by a manufacturing activity; the manufacturing equipment does not lose its individuality after the production activity is finished and can participate in future activities. However, unless a distinction between an object and its service is important for the context to be clear, the following discussion will mention them interchangeably.

For practical reasons, it is sometimes inevitable to regard several inputs (or outputs for that matter) as being identical to each other although, more rigorously, they are not. For instance, three medical doctors are on duty in an emergency room and they are not equally capable. However, we just have to regard them as equal in capability unless a way has been found to differentiate them and it is important to make such a differentiation for the purpose of measuring productivity.

Four broad categories are often constructed by productivity researchers and practitioners to classify inputs:

- (1) Labor inputs
- (2) Government goods and services
- (3) Capital inputs
- (4) Outside goods and services.

Each category may have different names and contents on different occasions. Sometimes there is not much theoretical reason to classify an input into one category instead of another. The classification is very often a compromise of the basic requirements of productivity measurement discussed in section 3.

6.1 Labor Inputs

All types of human resources are eligible to be classified into this category. However, if a type of human resource is not classified into this category, it is very often included in the outside goods and services. Sometimes a differentiation is made between those on the payroll list and others. For example, consider a case where security guard A is hired by a security service company but is assigned to firm X; on the other hand, security guard B is directly hired by firm X. A is not on the payroll list of firm X while B is. A is usually classified into the category of outside goods and services while B is included in the category of labor inputs. A more subtle situation arises when A is on the payroll list of firm X's headquarters but he is assigned to a division of firm X. How should A be classified as far as the measurement of the division's productivity is concerned? The answer to this question, and to many other questions about classification, is dependent upon how a compromise is made among the basic requirements of productivity measurement.

Very often a so-called labor productivity ratio or a so-called total factor (labor + capital) productivity ratio refers to only part of labor inputs, e.g. production-workers only. The quantity of labor input is usually expressed in terms of number of persons (including the full-time equivalents of the part-time workers) or man-hours. Different treatments also arise as to whether the number compensated or actually worked should be used.

If the dollar is chosen as the common denomination of inputs for a

productivity ratio, the conversion factor of a labor input is often its base-period unit wage.

6.2 Government Goods and Services

Almost every one receives some goods and services from governments (local, state, and federal), e.g., fire and police protection, highways, public school system, and national defense. It is very difficult, if not impossible, to find out exactly what government goods and services are enjoyed by a person, or a firm, or a production activity. The amount of tax paid is sometimes regarded as a surrogate of the government goods and services received; however, there is a large degree of inaccuracy involved.

There are two general principles of taxation [8]: benefit principle and ability-to-pay principle. The first principle says that people should be taxed in proportion to the government goods and services they receive. The second principle says that people should be taxed so as to create a socially desirable redistribution of income. The second principle clearly makes the amount of tax paid an inaccurate measure of the government goods and services received. Some taxes are mainly supported by the benefit principle, e.g., sales taxes, property taxes, license fees, etc. However, the relationship between paying these taxes and receiving benefits is questionable. Income taxes, on the other hand, are mainly supported by the ability-to-pay principle.

The question as to how to measure government goods and services has not been resolved and will most likely remain that way for quite a long time. In current practice, the sales taxes, property taxes, license fees, and other taxes which are mainly supported by the benefit principle are usually included in the category of government goods and services, after adjustment for inflation (or deflation as the case may be). Income taxes, on the other hand, are usually not included in this category in current practice. But income taxes may be used to determine capital inputs; this will be discussed in section 6.3.

6.3 Capital Inputs

Two basic approaches have been proposed by researchers and practitioners to deal with capital inputs. The first approach divides capital inputs into two groups: technical services and expected returns (after technical services). The approach has been used by many researchers and practitioners, among them Kendrick and Creamer [7]. The second approach does not deal with technical services directly but considers it within the context of expected returns. The second approach was suggested by Craig and Harris [2].

The first approach is more popular than all others. Technical services, as defined in this discussion, refer to services offered by capital goods and natural resources in production activities whenever they do not lose their individuality after the production activities are concluded. Human resources do not lose their individuality either after the production activities are concluded; however, their services are usually classified in the category of labor inputs or outside goods and services. It is important to note that not every type of capital good can provide technical services. Parts and semi-finished goods acquired from outside sources do not offer the technical services as defined in our discussion, since they lose their individuality after production activities are terminated; they are usually classified as outside goods and services. Similarly not every type of natural resource can offer technical services; an example is the fuel acquired from outside sources. On the other hand, plant and equipment, land, and patents, which keep their individuality after production, provide technical services.

Since two otherwise-identical capital goods (or natural resources) do not offer different technical services simply because one is owned and the other is leased, several researchers, like Kendrick and Creamer [7], believe that technical services should be all included in the category of capital inputs no matter if they are provided by owned or leased resources. However,

it is common to classify the technical services provided by leased resources in the category of outside goods and services.

For the purpose of measuring technical services, it is useful to think of the capital goods and natural resources, which still keep their individuality after production, as a storehouse of potential services; in other words, each contains a service potential. During production, a portion of the potential is consumed and the potential decreases. The difference between the service potential contained immediately before the production starts and that contained immediately after the production ends equals the services employed by the production activity. This concept is akin to one of those used by accountants in the context of depreciation, depletion, and amortization [5]. Since either the service potential or the services themselves are quite abstract, we need to find a way to make this concept operative.

Usually the number of hours (or other time units like days and months) operated or contracted is used as a surrogate of the quantity of technical services offered by capital goods and natural resources. However, this method alone does not address the whole issue since the quality of one machine-hour, for example, may be significantly different from that of another machine-hour no matter whether both are from the same machine or not. In other words, we need a conversion factor (or weight) for each type of technical service. An accounting depreciation procedure is often used to obtain an appropriate conversion factor if the capital good or natural resource involved is owned. Note that the purchase cost of the owned capital good or natural resource should be in base-period dollars before the depreciation procedure is carried out, in order to have a meaningful productivity ratio. On the other hand, the base-period rental rate is often used as the conversion factor if the capital good or natural resource involved is leased.

The conversion factor based upon the accounting depreciation procedure is usually

different from that based upon the rental rate even though the underlying services have the same quality. The outcome is not surprising since firstly a firm has several accounting depreciation procedures to choose from, secondly the firm has to estimate the residual value and service life to carry out the depreciation procedure, and thirdly the rental rate reflects not only the technical services but also the returns expected by the lessor.

As mentioned earlier, the quality of one machine-hour may be quite different from that of another machine-hour even though both are from the same machine. Wear and deterioration make the machine offer services of declining quality through time. With maintenance and repair, it is still questionable that the original quality can be kept. The activity of maintaining and repairing is itself a production activity. On the one hand, it employs various inputs such as labor, capital, and outside goods and services; on the other hand, it produces an output which is represented by an increase in the service potential of the machine involved. The output serves later as inputs to other production activities. Obviously, the output of maintenance and repair has a very abstract nature.

We often let the cost incurred by the activity of maintaining and repairing be a surrogate of its abstract output, and select an appropriate accounting depreciation procedure to depreciate the cost. The depreciation of the cost then becomes the technical services employed by other production activities.

We next discuss the second group of capital inputs - expected returns. All the assets shown on the balance sheet are owned by the firm. But why does the firm own these assets?

Take **cash** balances for example. Keynes listed three motives for cash balances to be held [3]:

- (1) Transactions motive - Cash balances are held because of the convenience they may generate in the planned purchase of goods

and services.

- (2) Precautionary motive - Cash balances are held because of the convenience they may generate in the unforeseen opportunities of advantageous purchases. In other words, transactions motive is for the planned purchases while precautionary motive is for the unplanned purchases.
- (3) Speculative motive - Cash balances are held because of the speculation on the future prices of other non-cash goods, services, and financial assets. One may postpone purchasing goods and keep cash if he speculates on a decline in the prices of the goods in the future.

Take inventories as another example. Researchers in operations management usually classify various inventories into four different classes [4]:

- (1) Cycle stock - Due to the principle of economy-of-scale, a larger quantity than currently needed is purchased or manufactured to take advantage of quantity discounts or to save setup costs. The extra quantity is cycle stock.
- (2) Seasonal stock - Due to seasonal factors, a larger quantity than currently needed is purchased or manufactured to satisfy peak demand in future periods.
- (3) Safety stock - It is the additional inventory carried to protect against uncertainties in demand or supply.
- (4) Pipeline stock - Due to technology and logistics limitation, raw materials cannot be converted into finished goods instantly and hence inventories of goods-in-process exist inevitably. These inventories are called pipeline stock.

Of course, an inventory may be held due to speculation on the future prices of goods involved. However, traditionally price speculation is not the major

consideration in the field of operations management.

One may easily realize that the three motives proposed by Keynes to hold cash balances and the four motives proposed by researchers in operations management to hold inventory are very similar. In short, cash balances and inventories are held because, by doing so, a positive net benefit (benefit - cost) is expected to be realized. In other words, a positive return on cash balances or inventories is expected.

The same expected-return argument applies to all other assets owned by the firm, including for example an unwanted inventory that resulted from a rosy forecast. The reason is that the funds tied in the extra inventory are associated with an opportunity cost. It is the expected returns on the owned assets which constitute the second group of capital inputs.

The difference between cash and cash balance, raw material and inventory of raw material, etc. can be confusing. In short, cash and raw material are flow variables while cash balance and inventory of raw material are stock variables. Similarly, machine (representing a service potential) is a stock variable while the service offered by the machine is a flow variable.

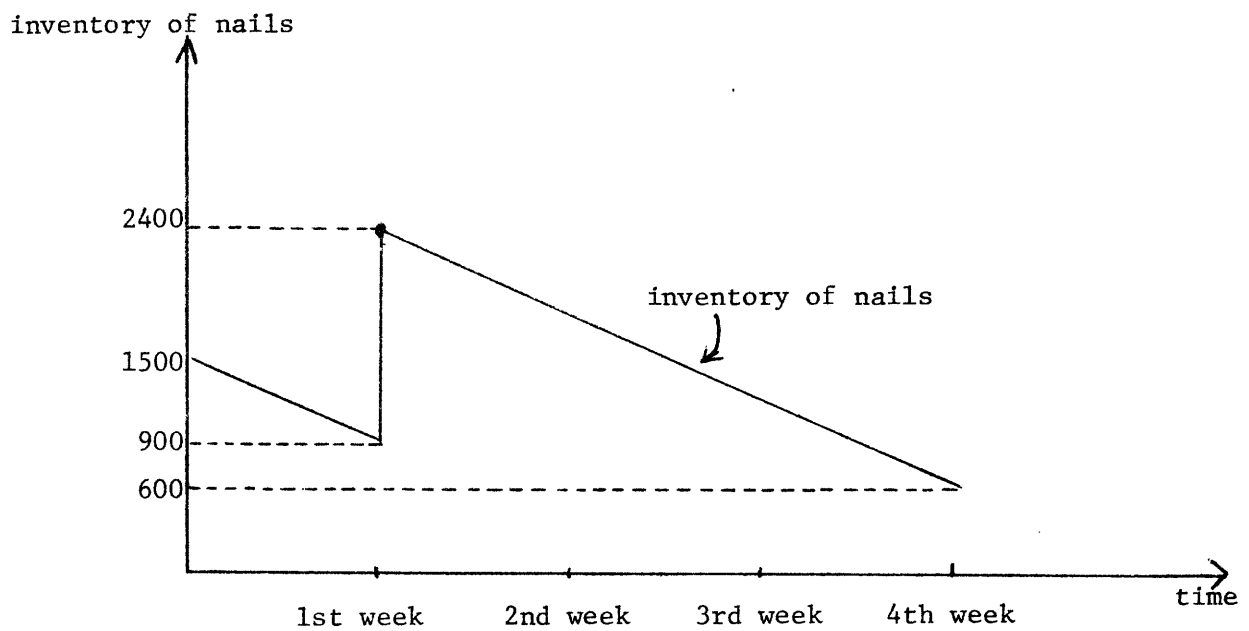
Let us use an example to illustrate the distinction between the raw material, which is classified in the category of outside goods and services, and the inventory of raw material, whose expected return is classified in the category of capital inputs. A shoemaker has a production schedule of 25 pairs of shoes each week for four weeks. Twenty nails are needed for each pair of shoes. Since he is not sure if he will have to alter his production schedule due to unexpected increases in the shoe demand, he decides to purchase a total of 3000 nails for the four week period. He has two purchase plans available to him. Plan 1 allows him to purchase 1500 nails at the beginning of the first week and another 1500 nails at the beginning of the second week. Plan 2 allows him to purchase 3000 nails at the beginning of the first week

at a discount price. At any rate, it turns out that he manufactures 30 pairs of shoes for each of the next four weeks. The two diagrams in Figure 6.1 show how the inventory of nails changes during that period if the shoemaker chooses plan 1 and plan 2, respectively. The average inventory of nails would be
$$\frac{(1500 + 900) \times 1/2 + (2400 + 600) \times 3/2}{4} = 1425 \text{ nails under plan 1}$$
 and
$$\frac{(3000 + 600) \times 4/2}{4} = 1800 \text{ nails under plan 2.}$$
 However, the number of nails which have been physically used to manufacture the 120 pairs (= 30 pairs per week \times 4 weeks) of shoes is 2400 (= 20 \times 120) under either plan.

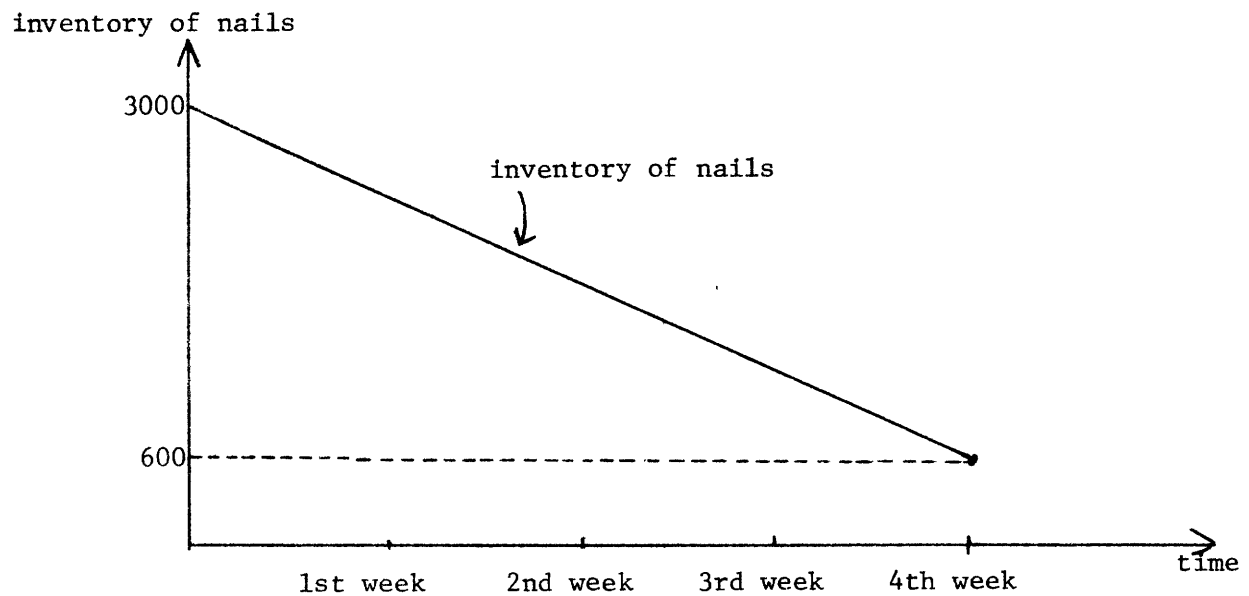
Suppose we want to measure the productivity of the shoemaking operation during the four weeks. The 2400 nails will be classified as outside goods and services, while the expected return on the inventory of nails will be classified as a capital input. The inventory of nails, as shown in Figure 6.1, is a function of time. For simplicity, the whole inventory curve can be represented by its average value, which is 1425 nails under purchase plan 1 and 1800 nails under plan 2. Sometimes due to the difficulty in data collection, the whole inventory curve is represented by the average of beginning inventory and ending inventory, which is 1050 ($= \frac{1500 + 600}{2}$) nails under plan 1 and 1800 ($= \frac{3000 + 600}{2}$) nails under plan 2.

How to measure the expected return on the owned assets? The researchers in productivity usually take the following five steps:

- (1) Restate the base-period net income figure in base-period dollars.
- (2) Restate the base-period asset values in base-period dollars, and sum the restated values over all the assets owned in the base period.
- (3) Divide the outcome in step (1) by the outcome in step (2) to obtain the base-period rate of return.
- (4) Restate the measured-period asset values in base-period dollars, and sum the restated values over all the assets owned in the



(a) Purchase plan 1 is adopted



(b) Purchase plan 2 is adopted

Figure 6.1 Inventory of Nails

measured period.

- (5) Multiply the outcome in step (3) by the base-period rate of return to derive the expected return on the total assets owned in the measured period.

In other words, the rate of return in the base period is regarded as the expected rate of return for the measured period. Thus, the restated value of the total assets in the measured period multiplied by the rate becomes the expected return for the measured period.

The first step is necessary since not every income-statement item of the base-period has its value stated in base-period dollars. The two most significant items are cost of goods sold and depreciation. Several inventory-flow methods (e.g., lifo, fifo, average cost, specific cost identification, etc.) are available for accountants to use in calculating the cost of goods sold. Depending upon the method adopted, the accounting value of cost of goods sold may or may not reflect purely the base-period cost. The accounting depreciation is calculated based upon the historical cost which again may or may not reflect the base-period cost. Hence, the accounting values of cost of goods sold, depreciation, and several other items of the base-period income statement should be restated in base-period dollars. The resulting new figure for the base-period net income then reflects the base-period price structure.

Steps (2) and (4) restate the asset value in base-period dollars. However, it is sometimes difficult to get the average value due to the wide fluctuations in value during a period. For example, it would be difficult to calculate the average value in the case shown in Figure 6.2, which often occurs for inventory or cash balance. To simplify, the average of the beginning and ending values is usually adopted.

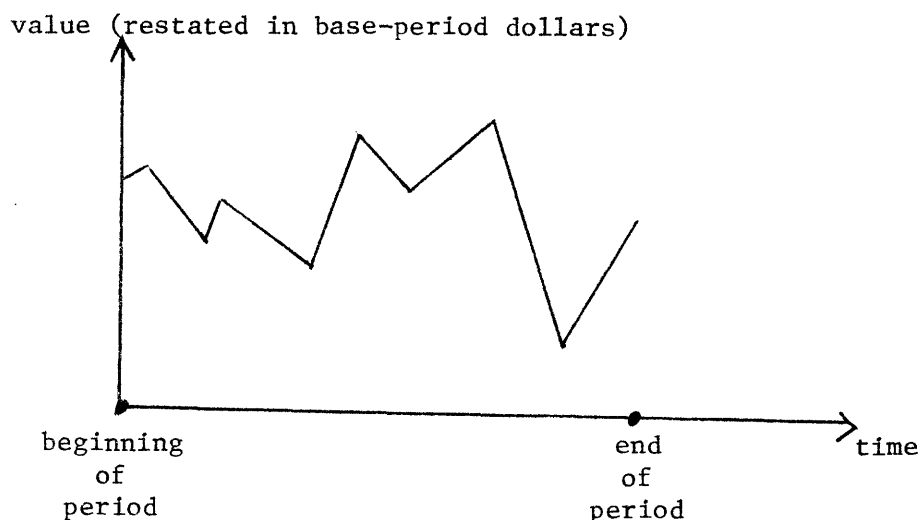


Figure 6.2 Example of Fluctuating Asset Value

The net income figure can be either that obtained after income taxes or before income taxes. If the net income after income taxes is used, then the income taxes should be classified as government goods and services in both the base and measured period. On the other hand, if the net income before income taxes is used, the part of government goods and services represented by the income taxes has been included in the category of capital inputs and hence is excluded from its original category. Kendrick and Creamer [7] adopted the second alternative and considered only indirect business taxes in the category of government goods and services.

The net income figure can also be either that obtained before or after interest expenses. Typically, the figure before interest expenses is used whenever the financing activities are not included in the production activity.

Also, the asset value can be either gross or net of accumulated depreciation. The gross value may be more suitable if the expenditures on maintenance and repair are expensed while the net value may be more suitable if they are capitalized.

The second approach in dealing with capital inputs eliminates the difference between technical services and expected returns but treats both within the

context of the latter. There are several different versions of this approach. One version is a natural extension of the first approach. This uses the net income before depreciation in calculating the base-period rate of return; by doing so, the expected return on the total assets of the measured period includes the technical services of the owned assets already. The technical services offered by the leased assets are then classified as outside goods and services under this version.

Another version is proposed by Craig and Harris [2]. The technical services and expected returns of an asset in various periods are represented by a series of equal receipts (or payments), called annuities. The acquisition cost (restated in base-period dollars) is the present value of the annuities, the expected number of periods in service is the number of periods of annuities, the expected rate of return on the asset is the annuity rate, and the value of the service in each service period is the annuity. The values of any three of the preceding four items can determine the value of the remaining one. Accounting records can usually tell us the acquisition cost and the expected number of periods in service. So if we know the expected rate of return, we can easily calculate the value of the services offered in each service period. Craig and Harris used the base-period cost of capital as the expected rate of return; the base-period cost of capital is a weighted average of base-period rates of return on debts, preferred shares, and common shares. Conceivably, other types of rate of return, such as the ratio of base-period net income (before or after interest expense, before or after income taxes) to the base-period asset value, can also be used.

6.4 Outside Goods and Services

Any goods and services acquired from outside sources can be classified into this category. Human services are always acquired from outside sources since the firm cannot own any person; government goods and services, and

services offered by leased capital goods and natural resources are also acquired from outside sources. However, due to their special characteristics and importance, a specific category has been established for each of them in most cases. As a result, the category of outside goods and services is left basically with the raw materials, semi-finished goods, electricity, fuels, office supplies, etc. A classification system should be flexible enough to meet special needs or constraints. A category is established because the goods and services included share some common characteristics which make the constituents important as a group for the purpose of measuring productivity. For example, we can single out electricity and fuels and establish a category of energy inputs or we can put all human resources into the category of outside goods and services, if necessary.

What we mean by "outside" deserves further explanation. As mentioned earlier, a production activity may be disaggregated into two or more subactivities or join other activities to form an expanded activity. A productivity ratio can be established for any of these. To explain the meaning of "outside" as used here, let us view a production activity as being composed of two or more subactivities. Any input employed by a subactivity which is not an output of some other subactivity is an input acquired from outside by the (aggregate) production activity. If we measure the firm's productivity, then the goods transferred from one division to another are not inputs for the firm. Nevertheless, if we measure a division's productivity, the goods transferred from other divisions to this division are said to be acquired from outside and hence eligible for inclusion in the category of outside goods and services.

7. Outputs

Two major categories can be used to classify outputs: goods for external use, and goods for internal use. The first category includes all the goods (tangible or intangible) which will be delivered to the outside environment once completed. The merchandise to be sold to customers and the goods to be delivered to other divisions are included in the first category. The second includes all the goods (tangible or intangible) that provide inputs to the same production activity in the future.

Some inputs are omitted from a productivity ratio purposely when a partial ratio is constructed. In general, however, every output is expected to be included in a productivity ratio, no matter if it is a total ratio or a partial ratio. Some production activities produce very abstract outputs, for example, R&D, advertising, and educational programs. In these cases, the outputs produced are sometimes omitted from a production ratio which was originally designed to cover all the activities of a firm or division. In such instances, the corresponding inputs must also be omitted.

If the output quantities are all available, then the numerator of a productivity ratio can be obtained by directly aggregating these quantities with appropriate conversion factors (weights). The conversion factor for a good-in-process should be parallel to the conversion factor for the corresponding finished good. For example, the conversion factor for a good-in-process should be related to unit man-hour if the conversion factor for the finished good is the unit man-hour. Due to the existence of an infinite number of completion percentages (from close-to-zero to one), there exist an infinite number of types of goods-in-process in correspondence to the same finished good. The whole spectrum of goods-in-process is usually divided into several ranges either arbitrarily or according to the physical production stages. Each range has one conversion factor which is an average over its own range.

To aggregate the goods-inprocess in various ranges and finished good together, we use the following formula:-

$$\begin{aligned} & (\text{conversion factor of the finished good}) * (\text{quantity of the finished} \\ & \text{good produced in the period}) + \sum_k (\text{conversion factor of the good-in-} \\ & \text{process in completion range } k) * (\text{quantity of the good-in-process in} \\ & \text{range } k \text{ at the end of the period} - \text{quantity of the good-in-process} \\ & \text{in range } k \text{ at the beginning of the period}) \end{aligned}$$

The conversion factors for the goods-in-process, as used in this formula, should be the accumulated ones. For instance, if the conversion factor of the finished good is the base-period unit machine-hour, then the conversion factor of the good-in-process in a particular range should be the base-period unit machine-hour accumulated up to that range (inclusive). Several examples of conversion factors for good-in-process and the corresponding finished good are given in Table 7.1.

If some output quantities are not available, then the detour described in section 5 may be necessary. The detour involves deflation of appropriate dividends by appropriate indices. Suppose that a certain number of finished goods have their base-period unit prices as the conversion factors and their quantities produced in the measured period are not available. The detour may involve the following three steps:

- (1) Adjusting the beginning inventory and the ending inventory of these finished goods from the cost basis to the measured-period value basis.
- (2) Obtaining the measured-period value of the finished goods produced in the measured period by using the formula:
$$\begin{aligned} & \text{measured-period sales revenue} + \\ & \text{measured-period value of the ending inventory of finished goods} - \\ & \text{measured-period value of the beginning inventory of finished goods.} \end{aligned}$$

Table 7.1 Examples of Conversion Factors for Good-in-Process and the Corresponding Finished Good

Conversion factors for finished good	Conversion factors for good-in-process
base-period unit man-hour	<ul style="list-style-type: none"> - base-period unit man-hour accumulated up to the range - base-period unit man-hour for the finished good * percentage of completion up to the range
base-period unit price	<ul style="list-style-type: none"> - base-period unit cost accumulated up to the range - base-period price for the finished good * percentage of completion up to the range
base-period value added added by labor	<ul style="list-style-type: none"> - base-period unit labor cost accumulated up to the range - base-period value added by labor for the finished good * percentage of completion up to the range

- (3) Deflate the measured-period value of finished goods produced in the measured period by an appropriate price index.

To obtain a better result, the heterogeneous finished goods are partitioned into several relatively homogeneous groups and the three steps mentioned above are applied to each group separately.

As we mentioned in section 6, machine maintenance and repair, which is a production activity, produces an output represented by the increase in the service potential of the machine. This concept is abstract and a way needs to be found to make the concept operative. Parallel to accounting procedures, the expenditures on maintenance and repair are taken as the increase in the

service potential and become the output of the activity. This output later provides services to other production activities. Some other production activities, such as the company's cafeteria shop, educational programs, advertising and R&D, also produce abstract outputs just as machine maintenance and repair does, and hence may be treated similarly as far as productivity measurement is concerned. However, this treatment has one disadvantage; a total productivity ratio of any of these activities is always one if the conversion factors of inputs are unit prices. This result is not satisfactory. We have to turn to other alternatives to obtain a more satisfactory result if we want to measure the productivity of any of these activities. Section 8 will discuss this issue again. It suffices to say here that if machine maintenance and repair, cafeteria shop, educational program, advertising, and R&D are included in a broader production activity (for example, the whole division or the whole firm), then the use of R&D's input cost as its output (or the use of cafeteria's input cost as its output, etc.) is acceptable as long as the input quantities involved in R&D are not significant. Sometimes a productivity ratio which is designed to cover the whole division or the whole firm omits R&D, cafeteria, etc. If these activities are omitted, both their outputs and inputs should be omitted from the numerator and denominator of the ratio.

Abstract outputs are not the only problem in dealing with the numerator of a productivity ratio; new model and new product present another set of problems. Since these products do not exist in the base period, we are faced with the following question: what would be the conversion factor for the new model (or new product) if it existed in the base period?

New model and old model (of the same product) usually share the same major components and have essentially the same function; but they may differ in quality. The conversion factor of the old model offers a basis for the conversion factor of the new one. If the deflated cost, i.e., the cost in base-

period prices, of the new model is 125% of the deflated cost of the old model, then the conversion factor of the new model may be 1.25 times as large as that of the old one since it can be argued that 25% more quantity (or quality) is embodied in the new model than in the old model. Alternatively, if the deflated selling price of the new model is 130% of the deflated selling price of the old one, then the conversion factor of the new model may be 1.3 times as large as that of the old one since it can be argued that purchasers derive more utility from the new model than from the old one, otherwise they would not buy the new model at a higher price. It should be noted that the first treatment will result in a situation where a total productivity ratio remains the same for both models if the unit prices are used as the conversion factors of inputs and the same number of units of output has been produced for both models.

The difference between new product and new model is not dramatic in most cases since many new products are either functionally related with existing products or share some components with existing products. Hence, the two treatments of new models can also be applied to the new product in many cases.

8. Knowledge Worker

The knowledge worker has to exercise a significant amount of judgement and creativity in performing his job. This is in contrast to the worker who merely follows the standardized procedures without exercising his judgement and creativity to a great extent.

Who are these knowledge workers? It is not easy to tell simply from job titles. A repairman is a knowledge worker in most cases because he has to diagnose the broken machine and repair it in an appropriate way, but a repairman may not be a knowledge worker in some cases if he only does what other repairmen or a standard repairing procedure asks him to do. Similarly, a

secretary is a knowledge worker in most cases because he has to schedule appointments, meet people and answer a variety of questions, but a secretary may not be a knowledge worker in some cases if he does nothing but typing.

Generally speaking, the following persons are considered as knowledge workers: managers, foremen, repairmen, secretaries, salespersons, lawyers, accountants, consultants, programmers, medical doctors, nurses, security guards, researchers, purchasing agents, travel agents, etc. Both blue- and white-collar workers can be (but do not have to be) knowledge workers.

The production activity which involves knowledge workers' services as an input produces less quantifiable and qualifiable output than the activity which does not. The amount of judgement and creativity exercised by a knowledge worker explains why. As mentioned earlier, machine maintenance and repair, R&D, training program, security guard, and etc. have to either be excluded from productivity measurement or be handled by an unsatisfactory method in productivity measurement, due to the abstract nature of their outputs. These treatments are acceptable only if the amount of resources used by these activities as inputs is not significant. When this is not the case, they have to be addressed directly.

The whole nation has an interest in analyzing the productivity of these activities due to a persistent shift of workers from farm and blue-collar jobs to white-collar jobs. As a percentage of total work force in America, the number of farm workers has decreased from 17.4% in 1940 to 2.8% in 1979, the number of blue-collar workers has decreased from 51.5% in 1940 to 46.3% in 1979, but the number of white-collar workers has increased from 31.1% in 1940 to 50.9% in 1979. Since more than half of the total work force is involved in white-collar jobs, it is important to analyze the productivity of white-collar workers. Although white-collar workers do not have to be knowledge workers, they are likely to fit this category because of the characteristics of their

jobs.

The interest also exists at the firm level. Many firms, e.g., banks, consulting firms, CPA firms, law firms, security guard service companies, secretarial service companies, hospitals, nursing homes, fast food restaurants and advertising firms rely essentially on the activities involving a significant number of knowledge workers. Even the traditional so-called manufacturing firms are very active in many of these activities. IBM, the largest manufacturer of computers, has about one half of its employees doing things like selling and leasing the computers, maintaining and repairing the machines, writing programs, and training customers. None of these activities has anything to do with the manufacture of computers; but these, together with the computer-manufacturing activity, produce a package which is sold to customers. Another example is R&D, which involves a significant number of knowledge workers and has become a major activity in both manufacturing and non-manufacturing firms. The expenditures on R&D have soared in several industries such as aerospace, drugs, information, instruments, and leisure-time where technology innovation is generally believed to be an important way for these businesses to keep (or in some case to regain) a competitive advantage over their counterparts in other countries. Due to the increasing complexity of government regulations and international business environment, the amount of money paid to lawyers, accountants and consultants has also soared in many firms. It is therefore very important that more research be done on the productivity analysis of these activities despite the difficulties in measuring their abstract outputs.

Since the mid-1960's, IBM has been using a so-called "Common Staffing System" or "Comparative Staffing System", [9], to measure the productivity of the following functions: general services, personnel, finance, plant engineering and maintenance, information systems and data processing, production control, procurement, manufacturing indirect, manufacturing engineering, quality assurance,

industrial engineering, materials distribution, facility services and product engineering. Each of these functions is called a model function in the Common Staffing System. Each model function is further disaggregated into several activities and a productivity ratio is constructed for each. The type of productivity ratio adopted by the Common Staffing System is the labor productivity ratio. Since the model functions are not directly related with the computer-manufacturing activity, the labor involved is only the indirect labor. Consequently, the Common Staffing System is often said to measure the productivity of indirect workers. Most of the workers involved are knowledge workers and hence the outputs of most of the activities have the quantification and qualification problems. The Common Staffing System uses a so-called indicator as the surrogate of output. The following are examples:

<u>Activity</u>	<u>Indicator</u>
secretarial services	indirect manpower
salary administration	total manpower
vendor billing	purchasing dollars
facility maintenance	square feet
safety	total manpower

IBM has identified about 140 activities and 60 indicators. Note that a model function can be disaggregated into more than one activity but not necessarily into all the 140 activities; and an activity can appear in more than one model function but not necessarily in all of them. Also note that an activity can be related to only one indicator but an indicator can be used for more than one activity.

The Common Staffing System can do time-series comparison as well as cross-sectional comparison. Every year, each of the IBM divisions which participate in the System submits the required data (i.e., the number of indirect workers and the level of the indicator) on each activity performed by that

division. For each activity, all the data of the same year are collected together and regression analysis is used to determine the trend or regression line. For example, division A reports that its secretarial services (activity) used 120 secretaries (number of indirect workers) to support a total indirect manpower of 1000 people. The data of the same year collected from division A and other divisions with regard to the secretarial services are plotted on a diagram as shown in Figure 8.1. A trend line is obtained by regression. The point on the trend line corresponding to the indirect manpower of 1000 indicates that the "trend" number of secretaries is 90. A norm index regarding the secretarial services is established for division A as follows:

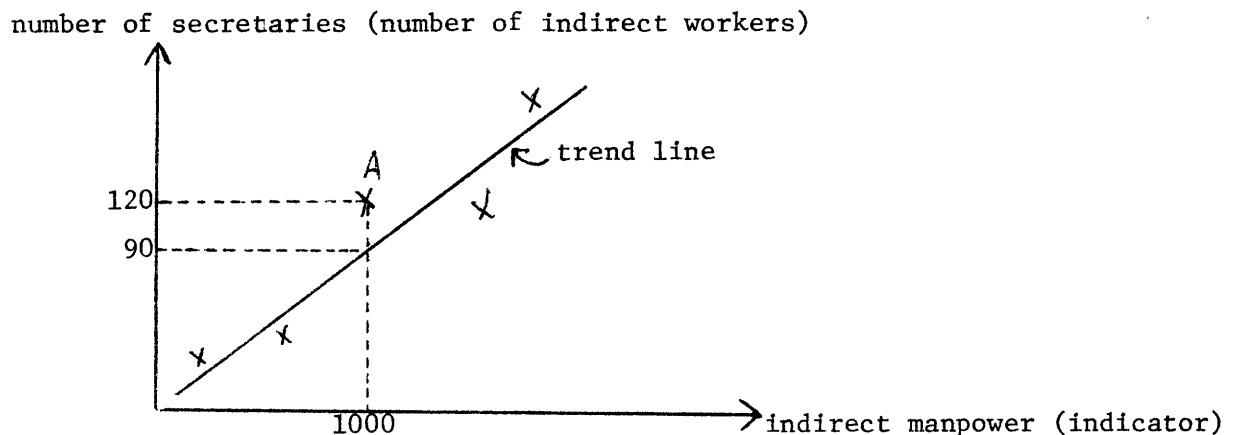


Figure 8.1 Example of Common Staffing System

$$\begin{aligned}\text{Norm index for division A} &= \frac{\text{actual number of indirect workers}}{\text{trend number of indirect workers}} \\ &= \frac{120}{90} \\ &= 1.33\end{aligned}$$

The norm index is used in doing cross-sectional comparisons. A norm index greater than one indicates that the division has used more indirect workers than normally required as far as the activity involved is concerned; a norm

index equal to one indicates that the division has used the normal number of workers; and a norm index smaller than one indicates that the division has used less indirect workers than normally required.

A productivity index is used in doing time-series comparisons. For example, division A used 120 secretaries to support an indirect manpower of 1000 in Year 0 (base year) and used 100 secretaries to support an indirect manpower of 900 in Year 1. The productivity index of Year 1 could be calculated as follows:

$$\text{Productivity ratio in Year 0} = \frac{120}{1000} = 0.12$$

$$\text{Productivity ratio in Year 1} = \frac{100}{900} = 0.11$$

$$\begin{aligned}\text{Productivity index in Year 1} &= \frac{\text{Productivity ratio in Year 1}}{\text{Productivity ratio in Year 0}} \\ &= \frac{0.11}{0.12} \\ &= 0.92\end{aligned}$$

A productivity index greater than one indicates that the division has used a larger number of indirect workers per unit of indicator in the measured year than in the base year as far as the activity involved is concerned. Note that the productivity ratio is defined as the ratio of input to output, instead of output to input, in the Common Staff System. Similarly, a productivity index equal to one indicates that the division has used the same number of indirect workers per unit of indicator in the measured year as in the base year; and a productivity index less than one indicates that the division has used less number of indirect workers per unit of indicator in the measured year than in the base year.

9. Conclusion

Productivity measurements are seldom perfect. A firm is advised to start its productivity measurement system by constructing a few important partial productivity ratios. It takes time for people to get accustomed to a new system and gain experience from it. Only after those who are concerned with or affected by the productivity measurement system become used to it and sufficient experience has been accumulated should a firm adopt a more sophisticated and complete system.

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